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Effects of Potassium Lactate, Encapsulated Citric Acid and Storage Temperature on Microbial Growth and Shelf Life of Pork Sticks

Yen-Kan Su
Utah State University

EFFECTS OF POTASSIUM LACTATE, ENCAPSULATED CITRIC ACID AND STORAGE TEMPERATURE ON MICROBIAL GROWTH AND SHELF LIFE OF PORK STICKS

by

Yen-Kan Su

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Yen-Kan Su

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ABSTRACT

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by

Yen-Kan Su, Master of Science

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Major Professor: Dr. Daren P. Cornforth
Department: Nutrition and Food Sciences

A new product, pork sticks, was developed. Optimum shelf life and safety were major concerns associated with this product. Potassium lactate (3%) or citric acid (0.5%, 0.56%, 0.60% or 0.66%) was added to pork sticks to determine their effects on microbial growth, sensory evaluation, and shelf life when stored frozen (-20°C), refrigerated (2°C), or at room temperature (22°C). Two raw materials, pork blade meat (shoulder meat; 91% lean, 9% fat) and regular 80:20 pork trim (80% lean, 20% fat) were used. The consumer panel preferred lean pork sticks made from blade meat over high-fat pork sticks made from regular 80:20 pork trim, regardless of the addition of potassium lactate (3%) or citric acid (0.5%). Pork sticks vacuum-packaged and held at 2°C or -20°C did not develop bacterial spoilage during six months storage. However, bacterial spoilage and oxidative rancidity occurred in the unpackaged control samples held at 22°C for one month. Incorporation of potassium lactate (3%) or citric acid (0.5%) decreased the color uniformity and red color intensity and increased the brown color intensity of the pork sticks made from blade meat. Vacuum-packaged

pork sticks with added citric acid (0.56%, 0.60% and 0.66%) stored at 22°C did not develop bacterial spoilage, but discoloration occurred after one month storage.

(82 pages)

INTRODUCTION

Intermediate moisture meat products are shelf-stable due to their low water activity (0.70-0.90) and moisture content (15-40%) (Ledward, 1981). Removal of water reduces water activity, but the soft texture desired in intermediate moisture meat products is lost if too much water is removed. Pork sticks, a new product, are favored by many people over jerky because of their tender texture. The moisture content of pork sticks is about 42%. This is higher than that of jerky. In preliminary work bacterial spoilage occurred in pork sticks that were vacuum-packaged and refrigerated for 60 days. The water activity of the pork sticks was not measured, but may have been near 0.90 or above.

In fact, the water activity of a food may interact with various factors such as oxidation-reduction potential, temperature, pH, and chemical preservatives to create a preservation system. A concentration of 2% (w/w) of sodium lactate has a marked effect in lowering water activity (Chirife and Fortan, 1980). Sodium lactate (2%) in ham can inhibit microbial growth and extend shelf life two-fold (Anonymous, 1988). The addition of sodium lactate can reduce surface discoloration and microbial load of fresh pork sausages (Lamkey et al., 1991). Papadopoulos et al. (1991) pointed out that increasing the sodium lactate level (0-4%) can cause higher yields and darker, redder color with less gray surface area of cooked beef. Organic acids are widely used as antimicrobial agents for improving shelf life of meat products. The addition of citric acid decreases the pH and inhibits the growth of bacteria. Furthermore, this may create a noticeable tart flavor similar to that of fermented sausages.

According to Leistner et al. (1981), meat products that have $a_w < 0.95$ and pH < 5.2, $a_w < 0.91$, or pH < 5 require no refrigeration, and meat products at pH 5.0-5.2 or a_w 0.91-0.95 require refrigeration at 10°C or less. Therefore, shelf life of meat products can be extended by lowering a_w, temperature, and pH value.

This study was conducted to determine the effects of potassium lactate, citric acid, and storage temperature on microbial growth, sensory attributes, and shelf life of pork sticks.

LITERATURE REVIEW

Water Activity

A German botanist, Walter in 1924, was thought to be the first researcher to define the relationship between relative water vapor pressure and microbial growth (Bruin, 1991). Mossel and Westerdijk (1949) found that the relative humidity of the atmosphere in a closed space over a food had a good correlation to growth reactions of bacteria. However, the term "water activity" was introduced by Scott (1953) in a study on moisture requirements of Staphylococcus aureus. The concept of "water activity" is widely used as a food stability criterion for microbial spoilage and for other types of deterioration, such as rancidity. We now know that water activity is more closely related to the physical, chemical, and biological properties of foods than total moisture content.

Water activity is defined as the ratio of the equilibrium vapor pressure of the sample (P) to the equilibrium vapor pressure of pure water (Po) at the same temperature (Scott, 1957). Thus, water activity = P / Po and values range between 0 and 1. Water activity can also be defined in terms of solute concentration through its relation to Rault's Law: a_w (water activity) = P / Po = N2 / N1 + N2, in which N1 and N2 are the number of moles of solute and solvent in the system, respectively.

Water Sorption Isotherm

A water sorption isotherm is a plot which relates water activity and moisture content of a system at a given temperature. A schematic isotherm for a typical food material is shown in Figure 1 (Duckworth, 1974). In this figure region C represents strongly bound water which is believed to be nonfreezable at any time. Region B represents a water fraction less firmly bound than the region C. The water in region A

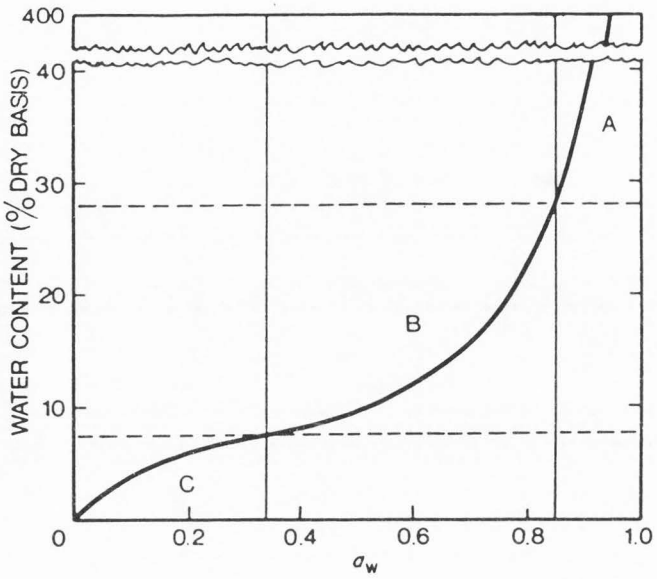

Figure 1. A generalized water sorption isotherm of a typical food material (Duckworth, 1974).

is more or less free water, mechanically trapped in the system.

Rockland (1980) suggested that for many products, a water sorption isotherm could be divided into three a_w segments representing three different types of water-binding of a food system. The segment at the a_w activity range of 0 to 0.25 is dominated by water bound by ionic groups such as NH_3^+ of proteins and COO^- groups of protein, pectin, and other polyuronic acids. The segment of the a_w range from 0.25 to 0.75 is related to water bound by hydrogen bonding to amide and hydroxyl groups in proteins and carbohydrate polymers. The segment lying at the a_w range of 0.75 to 1.0 is believed to represent water multilayers around proteins, carbohydrate polymers, and water in which the vapor pressure is reduced by dissolved solutes.

Intermediate Moisture Foods

With a wide acceptance of the concept of water activity, water activity and its modification have become central considerations in the development of intermediate moisture foods. According to Karel (1976), traditional intermediate moisture foods have moisture contents between 10 and 40% and water activities from 0.65 to 0.90. However, Corry (1976) has pointed out that the water activity range of intermediate moisture foods differs from author to author with values ranging from 0.70 to 0.85 (Brockmann, 1970), 0.60 to 0.85 (Plitman et al., 1973), 0.70 to 0.90 (Karel, 1976), and 0.60 to 0.90 (Collins et al., 1972). Corry (1976) suggested that a range of water activities from 0.70 to 0.90 is reasonable for intermediate moisture foods. Kaplow (1970, p. 899) defined intermediate moisture foods as, "One which can be eaten as is, without rehydration, and yet is shelf-stable without refrigeration or thermal processing."

Drying is frequently necessary to develop an intermediate moisture food which is shelf-stable without refrigeration. Kaplow (1970) reported that shrinkage and toughness are frequently associated with the drying process, except for freeze-drying.

Achieving a soft, moist intermediate moisture food frequently requires developing a food with as high a moisture content as possible for an acceptable water activity (Erickson, 1982).

Influence of Water Activity on Foodborne Bacteria

Scott (1957) pointed out that bacteria have an increase in the lag phase and a decreased growth rate and cell yield as water activity is reduced. According to the report of Sperber (1983), most bacteria have their maximum growth rates from a_w 0.990 to 0.995. Also, the minimum a_w values for growth of many foodborne bacteria were reported. The minimum values range from 0.99 for Moraxella / Acinetobacter-type organisms, isolated from fresh meat, down to 0.86 for Staphylococcus aureus. With the exception of S. aureus, the minimum a_w level for growth and toxin production by bacteria known to cause foodborne infection or intoxication is > 0.91 (Beuchat, 1981). Jakobsen and Murrell (1977) reported that the minimum a_w limit for sporulation appeared to be the same as growth. However, Baird-Parker and Freame (1967) and Jakobsen et al. (1972) found that spores can usually germinate at an a_w substantially below that which will permit growth.

A hypothetical mechanism of resistance of bacteria to reduced water activity has been proposed by Gould and Measures (1977). In order to maintain turgor, the intracellular a_w of cells is slightly lower than that of the external medium. However, cells are subjected to osmotic shock and rapidly lose water when they are placed in an environment of low a_w (Sperber, 1983). The decreased amount of intracellular water increases the internal potassium ion concentration and activates glutamate dehydrogenase which converts glutamate to α-aminobutyric acid (GABA). Some bacteria can reduce glutamate to proline. The GABA and proline are called compatible

solutes. The accumulation of glutamic acid or proline will help bacteria retain water when the cell is placed in a dry environment (Gould and Measures, 1977).

In reality, low a_w of a food interacts with other preservative factors such as oxidation-reduction potential (ORP), temperature, pH, and chemical preservatives to create a preservative system. Troller and Stinson (1975) found that the minimum a_w for growth of S. aureus is 0.91 in a sterilized shrimp product, but 0.86 in culture media. Mead (1969) has shown that the maximum ORP which would permit growth of Clostridium perfringens was decreased when the amount of NaCl in culture media was increased. Lotter and Leistner (1978) found the minimum a_w for growth of S. aureus to be 0.865 at 30°C, but increased to 0.878 with a reduction in temperature to 25°C. Baird-Parker and Freame (1967) have pointed out that C. botulinum type B could grow at a_w 0.960 and pH 7.0 or at pH 5.0 and a_w 0.997.

Influence of Water Activity on Yeasts and Molds

Beuchat (1983) pointed out that fungal spoilage of foods occurs more often than bacterial spoilage at $a_w < 0.85$, not because fungi grow faster at reduced a_w, but rather because the competitive effect of bacteria is absent. Troller (1979) stated that most yeasts and molds will not grow at a_w less than 0.87 and 0.80, respectively. However, the minimum a_w for growth of some fungi has been observed down to 0.61. Like bacteria, the lower a_w limit for growth of fungi depends partly on the characteristics of compatible solutes accumulated when they are exposed to a reduced a_w. The compatible solutes in fungi are polyalcohols, while bacteria accumulate glutamic acid and proline (Brown, 1974). Pitt and Christian (1968) found that higher a_w is required for spore formation of fungi than for spore germination. Northolt et al. (1977) studied the minimum a_w values for growth and production of mycotoxin of 11 test molds and found that the minimum a_w for growth was lower than for mycotoxin

production. The ability of molds to produce mycotoxins under conditions of a_w stress is also dependent on strain, nutrient availability, oxygen tension, temperature, and pH (Beuchat, 1983).

Water Activity and Shelf Life

Leistner et al. (1981) classified 37 German meat products into three categories (Table 1): highly perishable (pH > 5.2 and a_w > 0.95) requiring refrigeration at 5°C or less; perishable (pH 5.0-5.2 or a_w 0.91-0.95) requiring refrigeration at 10°C or less; or stable (a_w < 0.95 and pH < 5.2; a_w < 0.91; or pH < 5.0) requiring no refrigeration. The shelf life of storable products is limited by rancidity and discoloration rather than by microbial spoilage.

Methods of Measuring Water Activity

Freezing Point Depression Method. Based on Rault's Law, depression of the freezing point is directly related to the lowering of the vapor pressure above the solution compared to that above pure water at the same condition. The vapor pressure of the solution is determined from the freezing point depression by referring to standard tables and then converted to a_w. Prior (1979) stated that this method is most suitable for the a_w range of 0.8-1.0.

Salt-Impregnated Filter Paper Method. This method was proposed by Kvaale and Dalhoff (1963) and is based on the fact that a salt will not dissolve unless the surrounding humidity level rises to a point that is equal to the saturation moisture content of the salt.

Water Sorption Isotherm Method. In this method, the sample is placed in a desiccator containing a known weight of dried protein or microcrystalline cellulose and allowed to equilibrate. The protein or cellulose

Table 1. Storage categories of meat products based on the a_w and pH of the product, with recommended storage temperatures (Leistner et al., 1981).

Category	Criteria	Temperature of storage
Storable	$a_w \leq 0.95$ and $pH \leq 5.2$ or $a_w \leq 0.91$ or $pH \leq 5.0$	no refrigeration required
Perishable	$a_w \leq 0.95$ or $pH \leq 5.2$	$\leq +10\ ^{o}$
Easily perishable	$a_w > 0.95$ and $pH > 5.2$	$\leq +5\ ^{o}$

absorbs a certain amount of water depending on the original a_w of the sample. After the amount of water absorbed by the protein or cellulose is obtained, the water activity of the sample is read from a standard water sorption isotherm. Satisfactory results have been reported by Fett (1973), Prior et al. (1977), and Sloan and Lebuza (1976).

Graphical Interpolation Method. Landrock and Proctor (1951) proposed this method and found it to be a practical means of a_w measurement. Samples are placed in desiccators containing known relative humidities of saturated salt solutions and allowed to equilibrate for 2 to 4 hours. The a_w of the sample is determined by plotting % weight change (gain or loss) against a_w of saturated salt solutions. The intersection of % weight change with the center line (no weight change) represents the a_w of the sample. Kvaale and Dalhoff (1963) reported that this method is most suitable for determining the a_w of food products below 0.90.

Dew Point Method. In this method, the sample is placed in a chamber with a mirror, sample holder, and a means of detecting condensate on the mirror and allowed to equilibrate with the surrounding air space (Prior, 1979). The a_w is determined by cooling the mirror until droplets of water vapor form on the mirror, at which point the temperature is measured. The temperature is directly related to the a_w of the sample (Anagnostopoulos, 1973).

Electric Hygrometers. According to Prior (1979), the instrument consists of a sensor containing a hygroscopic material, usually LiCl, a sample chamber, and a potentiometer. The conductivity of LiCl, which depends on the relative humidity in the chamber above the sample, can be converted into the sample a_w by referring to standard calibration curves. Leistner and Rodel (1975) pointed out that the accuracy of the instrument is related to calibration against saturated salt solutions and use of a standard calibration curve.

Hair Hygrometer. The measurement of a_w of this instrument relies on the ability of human hair to stretch when hydrated. Troller and Christian (1978) stated that the instrument is less sensitive than many a_w instruments.

Psychrometer. A thermocouple placed in an equilibrated chamber containing a sample is cooled by Peltier cooling to condense water vapor on its surface. The rate of evaporation from the thermocouple is proportional to the psychrometer reading. The sample a_w is determined from a standard curve. Prior et al. (1977) reported that the Wescor psychrometer is suitable only for measuring a range of a_w of 0.935 to 1.0.

Vapor Pressure Manometer. Makower and Myers (1943) demonstrated that the vapor pressure of a food may be measured directly by a manometer. The sample is placed in a flask connected to a manometer and allowed to equilibrate for one hour at constant temperature. The vapor pressure is measured. The evaporated water is then removed and the vapor pressure of the remaining gases and volatiles is measured. The a_w of the sample is obtained by dividing the difference of the two readings by the vapor pressure of pure water at the same temperature. Vos and Labuza (1974) reported that the method is effective over an a_w range between 0 and 0.9 but is inaccurate at a_w above 0.9 due to temperature control problems.

Sodium Lactate

Sodium lactate has been used for more than 20 years in the food industry, primarily for its humectant properties (Reid, 1969). However, much research has been directed toward lactic acid to control microbial growth on carcasses and retail meats, but data are limited on use of sodium lactate (Papadopoulos et al., 1991).

A concentration of 2% (w / w) of sodium lactate has a marked effect in lowering water activity (Chirife and Fortan, 1980). Hammer and Wirth (1985) pointed out that sodium lactate can lower water activity in cooked liver sausages. Anonymous (1988) reported that up to 2% sodium lactate in ham can inhibit microbial growth and

extend shelf life two-fold. Maas et al. (1989) found that sodium lactate delays toxin production by Clostridium botulinum in cooked-in-bag turkey products. The addition of sodium lactate can reduce surface discoloration and microbial load of fresh pork sausages (Lamkey et al., 1991). Papadopoulos (1991) pointed out that increasing the sodium lactate level (0-4%) can cause higher cooking yields and darker, redder color with less gray surface area.

Berian et al. (1980) studied the structure of meat emulsions and its relationship to chemical additives and found that meat with sodium lactate added had slightly less emulsion stability than that of controls, but the difference was not significant.

Potassium Sorbate

Potassium sorbate is a white crystalline powder used to prevent mold growth in sausage casings and in other foods such as cheese but is not allowed for use in fresh meat (Robach and Sofos, 1982). However, Greer (1982) pointed out that psychrotrophic bacteria will not grow on fresh beef dipped in a 10% potassium sorbate solution. Myers et al. (1983) found that vacuum-packaged pork roasts stored at 5°C for 21 days have a 97-99% reduction in psychrotrophic bacteria if sprayed or dipped in 5% or 10% potassium sorbate solutions before packaging.

Citric Acid

Organic acids are widely used as antimicrobial agents for the improvement of the shelf life of meat products. However, the studies of using citric acid as an antimicrobial agent are limited. Crab meat is preserved without discoloration by treatment with citric acid or a citrate salt.

Direct acid addition in meat, to give a similar acidity level as that of fermentation, will cause loss of binding in meat blends and produce a softer and more crumbly texture. Citric acid encapsulated with hydrogenated palm oil will not melt

until the product is cooked above 125°F (52°C), avoiding premature acidulation (Bacus, 1986). According to Houston (1984), acetic acid, citric acid, phosphoric acid, and tartaric acid can be utilized to adjust and stabilize acidity in processed meat products at levels "sufficient for purpose."

MATERIALS AND METHODS

Experimental Design

In experiment 1, fresh pork blade meat (shoulder meat; 91% lean, 9% fat) and 80:20 regular pork trim (80% lean, 20% fat) were used to make pork sticks. For each raw material three different treatments were used, including control, potassium lactate added, and citric acid added. Potassium lactate (65% pure potassium lactate in solution, Archer Daniels Midland Co., Decatur, IL) and encapsulated citric acid (F.W. Witt & Co.,Yorkville, IL) were added at levels of 3% (w/w) and 0.5% (w/w), respectively. The initial % protein, % fat, % moisture, a_w, and pH of pork sticks were analyzed. A consumer panel of 35 people evaluated the pork sticks for preference on a 1-9 hedonic scale (1 = dislike extremely and 9 = like extremely). The sensory evaluation was conducted in the taste panel room in the Nutrition and Food Sciences Department with panelists seated in separate booths. Experiment 1 was replicated once.

In experiment 2, the pork sticks prepared in experiment 1 were stored frozen (-20°C), refrigerated (2°C), or at room temperature (22°C). Pork sticks were vacuum-packaged before they were stored in the freezer or refrigerator. Pork sticks held at room temperature were not vacuum-packaged because of the concern that anaerobic pathogens such as Clostridium botulinum might grow. Instead, they were dipped in 2.5% potassium sorbate solution (J.T. Baker Inc., Phillipsburg, NJ) for 30 seconds to inhibit mold, dried for 15 min in the smoke house at 38°C, and stored at room temperature. Microbial (both aerobic and anaerobic) plate counts were performed initially and every 30 days for 6 months (except for frozen samples which were evaluated every 90 days). To determine the shelf life of samples, a trained taste panel of 12 people evaluated nine different attributes for the pork sticks on a 1-7 scale at the same time the microbial plate counts were performed. Further panel evaluations were discontinued if a treatment was rated unacceptable for any attribute. Experiment 2 was replicated once.

In experiment 3, three different amounts of encapsulated citric acid (0.56%, 0.60%, and 0.66%) were added to pork blade meat to make the pH of final products to about 5.0, 5.1, and 5.2, respectively. All of these pork sticks were vacuum-packaged and stored at room temperature. The initial % protein, % fat, % moisture, a_w, and pH were measured. Microbial (both aerobic and anaerobic) plate counts and sensory evaluation were performed as described in experiment 2. TBA assay for rancidity was also done whenever sensory evaluation was performed.

Preparation of Pork Sticks

Pork (blade meat or regular 80:20 trim) was coarsely ground through a 3/8" plate and mixed with spices, salt, and potassium lactate or citric acid as needed (appendix A). Then the meat was ground through a 1/8" plate and extruded through a custom-made polypropylene head to form strips of 1/4" thick and 1 1/4" wide. The polypropylene head was removable and could be attached to the end of a 2 cm diameter stuffing horn when needed. The head could be firmly attached to the stuffing horn by tightening of two stainless steel screws placed so that they were tightened in the two parallel grooves on either side of the stuffing horn. After extrusion, meat strips (about three feet long) were placed manually on racks and cooked one hour at an oven temperature of 135°F (57°C), then four hours at 165°F (74°C), and finally at 185°F (85°C) until an internal temperature of 155°F (68°C) was reached. The final products were cut to 8.9 cm and vacuum-packaged in 15 x 30 cm clear laminated nylon-polyethylene bags (O_2 permeability = 0.6 g O_2 / 625 cm^2 / 24 hrs at 0°C; Koch, Kansas City, MO) or dipped in potassium sorbate solution, and stored frozen (-20°C), refrigerated (2°C), or held at room temperature (22°C).

Microbial Plate Counts

Aerobic and anaerobic plate counts were completed according to the "Guidelines for Microbiological Evaluation of Meat" (Kotula et al., 1980). For preparation of a serial dilution of samples, 25 grams of meat product were added to 225 ml of diluent and blended for two minutes for the first dilution. The number of dilutions plated depended on the estimated level of bacteria on the sample to be evaluated. Standard plate count agar (Difco, Detroit, MI) was used as the growth medium. For anaerobic plate counts, plates were incubated in an anaerobic jar (BBL Gas Pack System, Becton Dickinson and Co., Cockeysville, MD). The incubation was performed at 35°C for 48 hr.

pH Measurement

pH was measured after blending a 10-gram sample with 90 ml distilled water for 1 min with a polytron homogenizer. The pH of homogenates was measured with an Orion pH electrode and Orion Research pH meter Model 601 A (Cambridge, MA).

Moisture Measurement

Samples were blender-homogenized in advance. Then about 2 grams of homogenized sample were placed in a 2" diameter aluminum dish (VWR Scientific Company) and oven-dried for 16-18 hr at 100-102°C (Blue M Electric Company, Blue Island, IL). The sample was cooled in a desiccator for 15 min and reweighed. Percent moisture content of samples was then calculated as follows:

$$\% \text{ moisture} = (Wa-Wb) / Wa \times 100$$

where Wa = original weight of sample; Wb = final weight of sample (AOAC, 1980).

Fat Measurement

A homogenized sample (3-4 grams) was dispersed in a thimble with a small amount of sand and oven-dried for 6 hr at 100-102°C. A clean, dry receiving beaker was weighed accurately in advance. Then the thimble was placed in the condenser

bracket of a Labconco Goldfisch Fat Extraction Apparatus Model 35001 (Kansas City, MO) and the extraction of fat was performed for 4 hr using petroleum ether (J.T.Baker Inc., Phillipsburg, NJ). Extracted fat was collected in the clean, preweighed beaker. Percent fat content of samples was calculated as follows:

$$\% \text{ fat} = (Wc-Wb) / Wa \times 100$$

where Wa = original weight of sample; Wb = weight of beaker; Wc = weight of beaker and fat after extraction (AOAC, 1980).

Protein Measurement

A homogenized sample (0.5 g) was weighed on a 1.5" diameter filter paper, folded, and dropped into a 100 ml Kjeldahl digestion flask containing 10 ml sulfuric acid. Digestion was conducted with Labconco Rapid Digestor Model 23012 for 12 hr. Then the sample was distilled using a Labconco Rapid Kjeldahl Distillator until 50 ml distillate was collected in a flask containing 25 ml boric acid solution and four drops of Tashiro's indicator (0.25 g methylene, 0.375 g methyl red, and 300 ml 95% ethanol). Titration was performed after distillation with 0.1 N HCl. Percent protein was calculated using the following formula:

$$\% \text{ protein} = (Va-Vb) \times 1.4007 \times N \times 6.25 / \text{gram sample}$$

where Va and Vb = Volume of HCl required for the titration of sample and blank, respectively.; 1.4007 = milliequiv. wt of Nitrogen x 100 (%); N = normality of HCl; and 6.25 = protein factor for meat products (16%) (AOAC, 1980).

Water Activity Measurement by the Graphical Interpolation Method

About 3 grams of homogenized sample were placed in aluminum dishes and placed in six desiccators of known relative humidities containing different saturated salt solutions and held for 2-4 hr at 25°C. The saturated salt solutions were cupric chloride ($a_w = 0.67$), sodium chloride ($a_w = 0.75$), ammonium sulfate ($a_w = 0.79$), potassium

chloride (a_w = 0.86), potassium nitrate (a_w = 0.93), and potassium sulfate (a_w = 0.97). The percent weight change due to loss or gain of moisture was plotted against water activity, and the intersection of the plot with the zero weight change line represented the a_w of the sample (Landrock and Proctor, 1951).

TBA Assay

Homogenized sample (0.5 g) was combined with 3 ml of TCA-TBA-HCl reagent (15% w / v trichloroacetic acid; 0.375% w / v thiobarbituric acid; 0.25 N hydrochloric acid) and 9.5 ml distilled water and mixed thoroughly. The solution was heated in a boiling water bath for 15 min. Then the solution was centrifuged at 5000 rpm for 10 min to remove precipitate. The absorbance of the sample was determined at 535 nm against a blank that contained all the reagents minus the sample. TEP (1,1,3,3,-tetra-ethoxypropane) was used as standard for the determination of malonaldehyde concentration (Buege and Aust, 1978).

Trained Panel Evaluation

A 12-member panel was selected and trained. During training, panelists tasted pork sticks and participated in the determination of the terms used to evaluate samples. Nine attributes were chosen, including texture, color uniformity, red color intensity, brown color intensity, spicy flavor, acid flavor, rancid flavor, off flavor, and overall acceptability. Samples were evaluated on a 1-7 scale (appendix C). Evaluations were performed in the taste panel facility in the Department of Nutrition and Food Sciences. Panelists were seated in separate booths to prevent communication between panelists. Water was provided, and panelists were instructed to rinse their mouths between samples.

Data Analysis

For experiment 1, analysis of variance of treatment means for product compostion and consumer panel hedonic ratings was performed using the Stat View™ 512+ statistical package on a Macintosh SE computer (Apple Computer Co., Cupertino, CA). For experiments 2 and 3, analysis of variance of treatment means for trained panel ratings of various sample attributes was done using release 7.2 of Minitab© (State College, PA).

RESULTS

For experiment 1, Table 2 shows means for moisture content, protein content, fat content, a_w, and pH of pork sticks. Control treatments had higher moisture content than lactate and citric acid treatments regardless of the raw materials used. Control pork sticks made from blade meat contained more moisture than control pork sticks made from 80:20 trim. Similar protein contents were found in the pork sticks that were made from the same materials regardless of treatment. As expected, pork sticks made from 80:20 trim had higher fat content than those made from blade meat. The lower fat content of the control groups (for both raw materials) was associated with higher moisture content. Addition of potassium lactate had no effect on the pH of pork sticks when compared to the controls. However, citric acid had a significant influence in lowering the pH of pork sticks. The influence was not as great in the 80:20 samples. Compared with the control, incorporation of potassium lactate had a marked effect in lowering a_w of pork sticks. Addition of citric acid had a significant influence in decreasing a_w of pork sticks made from blade meat, but increased the a_w of pork sticks made from 80:20 trim.

The results of consumer panel evaluation of the six different treatments are shown in Figure 2. The three treatments made from blade meat had significantly higher scores ($p < 0.01$) than the treatments made from 80:20 trim. Although the mean score of control pork sticks made from blade meat was slightly higher than scores of lactate- or citrate-treated meat, there was no statistical difference among these three treatments. The results showed that panelists liked pork sticks moderately. The pork sticks made from 80:20 trim were given low scores by panelists. Thus, 80:20 pork trim was not used in any further experiments.

In experiment 2, the results of sensory evaluation of pork sticks stored frozen or

Table 2. Moisture content, protein content, fat content, a_w, and pH of pork sticks (experiment 1).

Treatment	% Moisture	% Protein	% Fat	a_w	pH
Control blade	33.89	44.21	14.04	0.87	5.91
Lactate blade	29.81	45.93	16.14	0.80	5.91
Citrate blade	29.98	45.74	15.75	0.83	5.29
Control 80:20	29.98	38.68	23.23	0.86	5.87
Lactate 80:20	23.37	37.12	27.55	0.80	5.88
Citrate 80:20	23.96	37.76	28.77	0.91	5.60

All values are the average of two replicates.

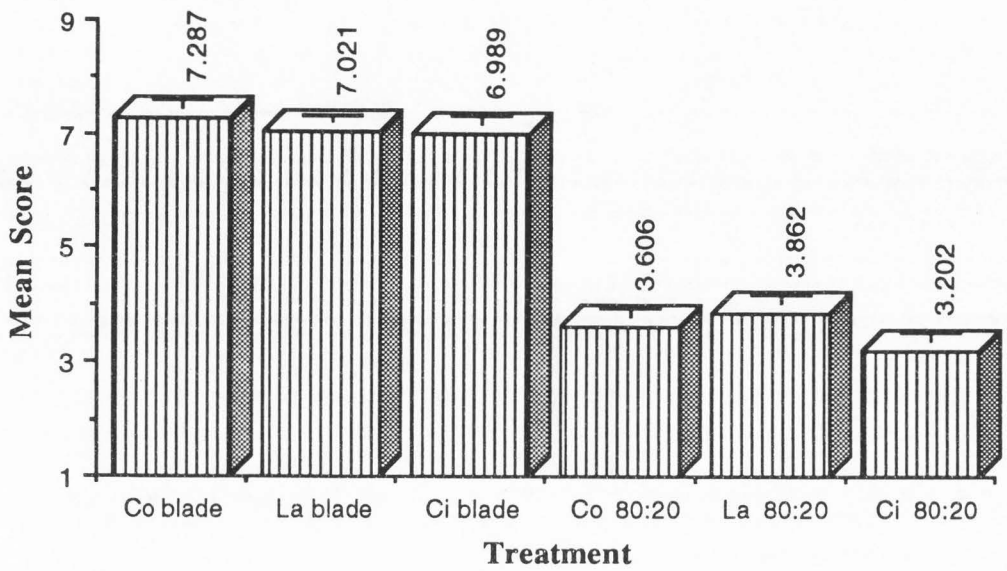

Figure 2. Mean scores for consumer panel hedonic ratings of pork sticks made from blade meat or 80:20 pork trim (experiment 1). All products were formulated to contain salt (1.38%), sodium nitrite (156 ppm), and spices. Treatments also contained 3% potassium lactate (La), 0.5% citric acid (Ci), or control with no additional antimicrobial agents added (Co). Scores: 9 = like extremely, 1 = dislike extremely.

refrigerated are shown in Figures 3-11. The addition of potassium lactate or citric acid significantly decreased the color uniformity of pork sticks ($p < 0.01$) when compared with controls (Figure 3). There was no interaction between treatment and temperature or between treatment and time. Potassium lactate and citric significantly ($p < 0.01$) decreased the red color intensity of pork sticks (Figure 4). In particular, pork sticks with added potassium lactate or citric acid had a steep decrease in red color intensity beyond five months storage ($p < 0.01$). Contrary to red color intensity, potassium lactate or citric acid significantly ($p < 0.01$) increased brown color intensity of the samples (Figure 5). These samples showed a steep increase in brown color intensity beyond five months storage ($p < 0.01$). Texture scores (Figure 6) decreased with storage time ($p < 0.01$). Due to vacuum packaging of the samples, the moisture present in the interior may have moved to the surface with storage time, softening the dry exterior skin. Samples stored at 2°C were less soft than those stored at -20°C. All treatments at 2°C decreased in spicy flavor intensity as the storage time increased (Figure 7). Frozen samples had a significantly higher spicy flavor intensity ($p < 0.05$) than did the refrigerated samples. Samples containing citric acid were significantly ($p < 0.01$) higher than the other two treatments for acid flavor intensity regardless of storage temperature and time (Figure 8). Samples stored at 2°C appeared to have a steep increase ($p < 0.01$) for rancid flavor intensity beyond five months storage (Figure 9). The rancid flavor intensity ratings after six months storage were, in order, citric acid > potassium lactate > control samples ($p < 0.05$). Rancid flavor intensity did not change for frozen samples with storage. The off-flavor intensity ratings also increased rapidly ($p < 0.05$) for citric acid and potassium lactate samples stored at 2°C after five months storage (Figure 10). Refrigerated control samples and frozen samples did not change much in off-flavor intensity during storage . There was no significant difference among treatments for overall acceptability score over all storage times for frozen samples and within five months storage for refrigerated

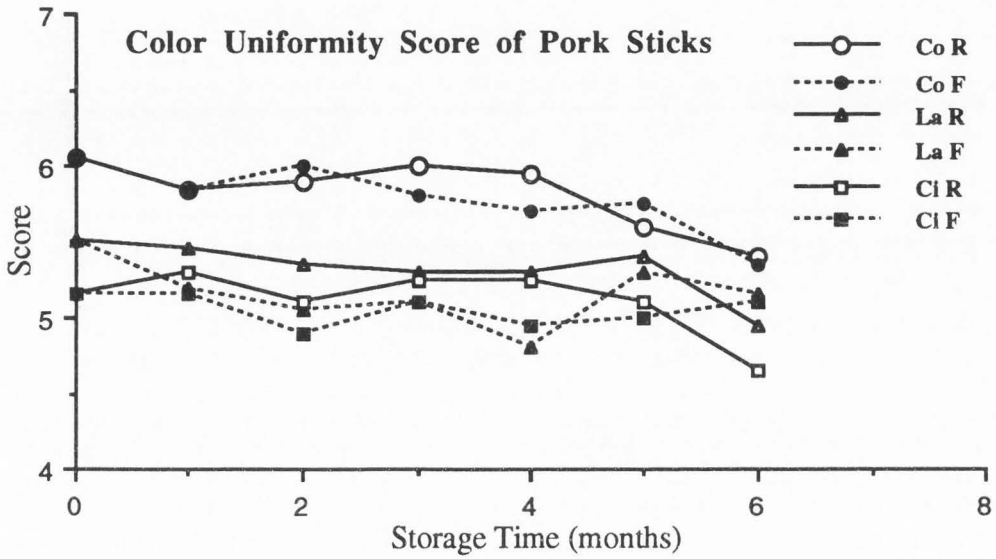

Figure 3. Color uniformity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = very uniform, 1 = very spotted or discolored. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

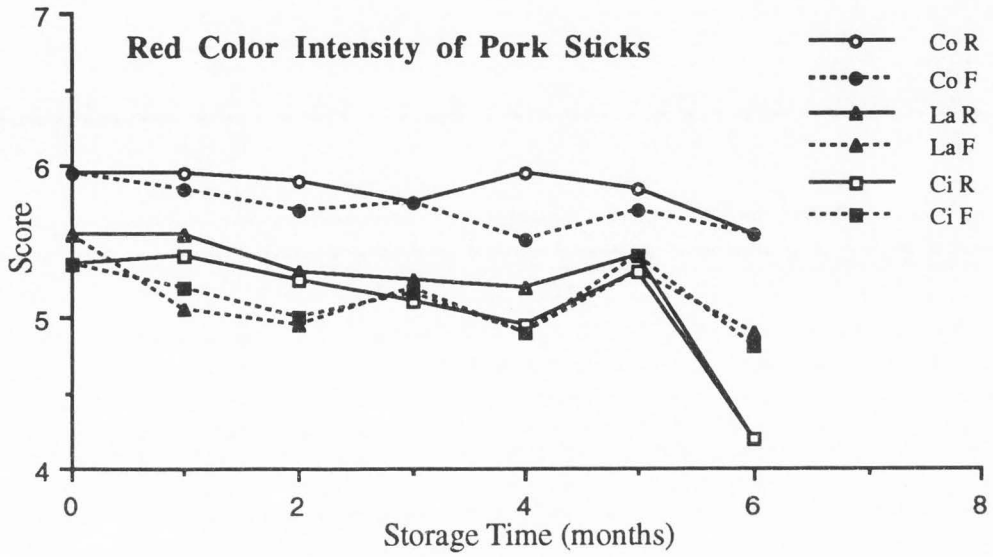

Figure 4. Red color intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = very intensely red, 1= not red. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

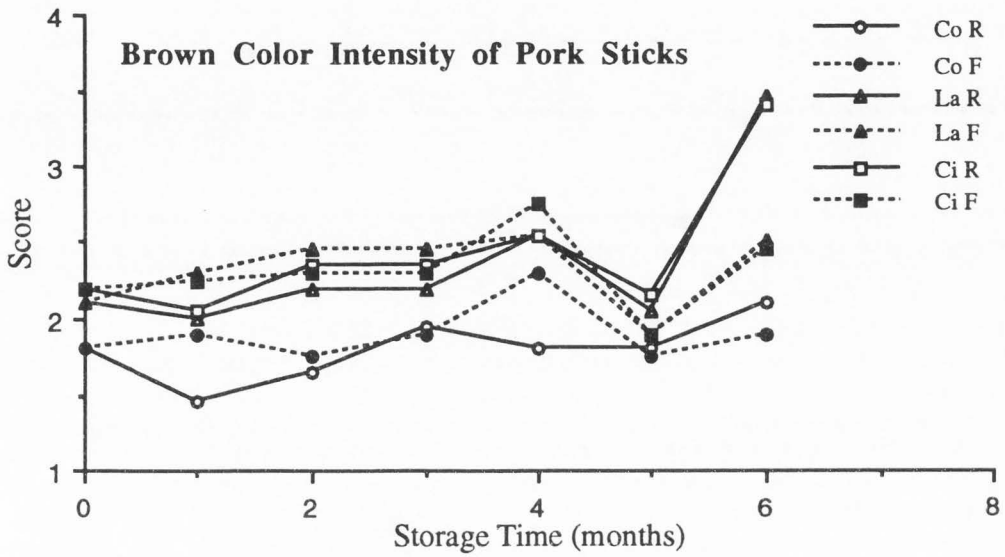

Figure 5. Brown color intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = very intensely brown, 1 = not brown. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

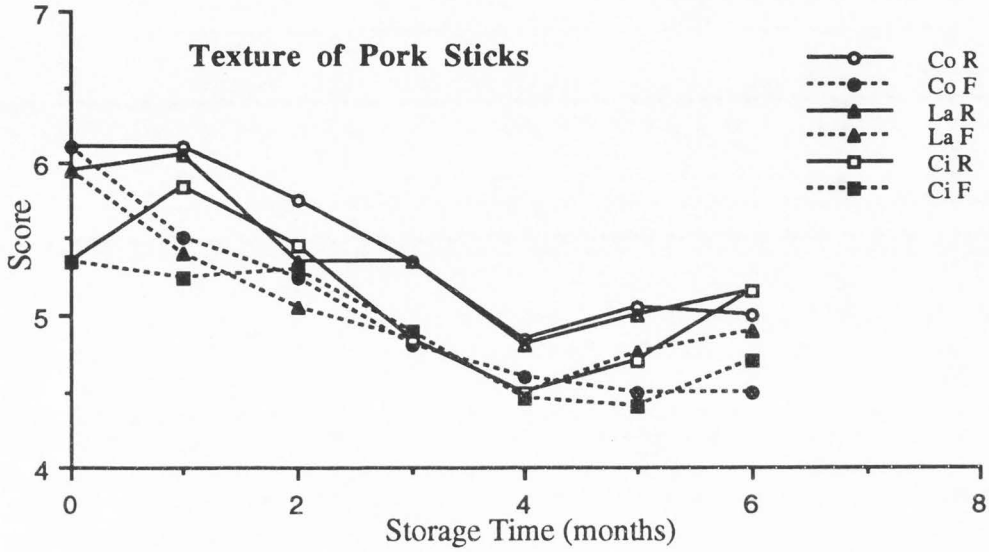

Figure 6. Texture of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = very hard,1 = very soft. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

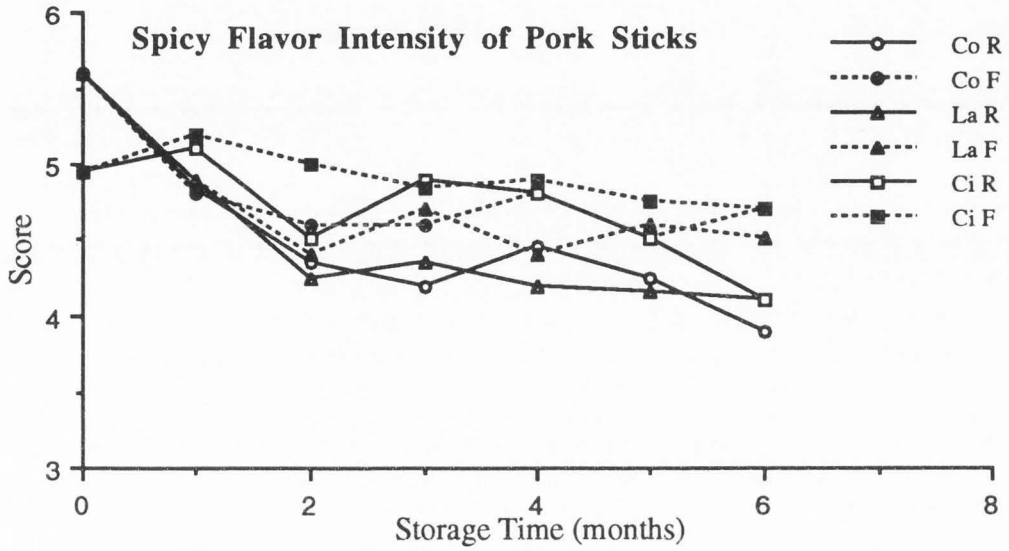

Figure 7. Spicy flavor intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = high intensity, 1 = not detectable. Co: control samples, La: lactate added, Ci: citric acid added, R = refrigerated, F = frozen.

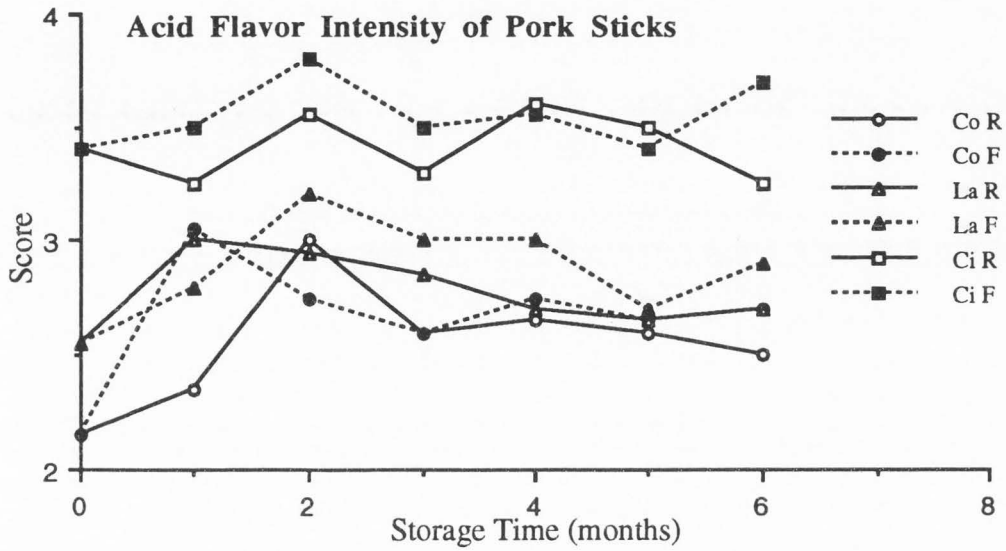

Figure 8. Acid flavor intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = high intensity, 1 = not detectable. Co: control samples, La: potassium lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

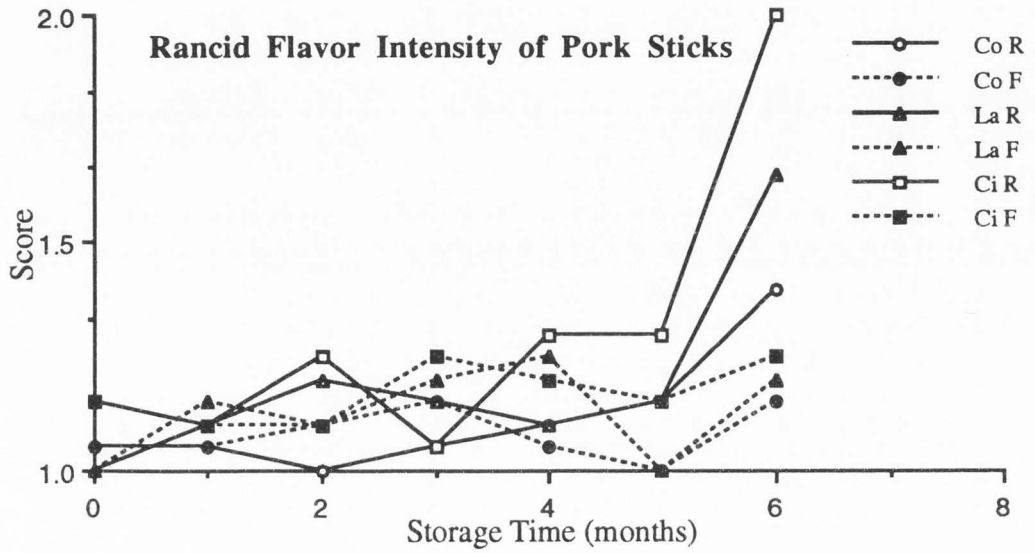

Figure 9. Rancid flavor intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = high intensity, 1 = not detectable. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

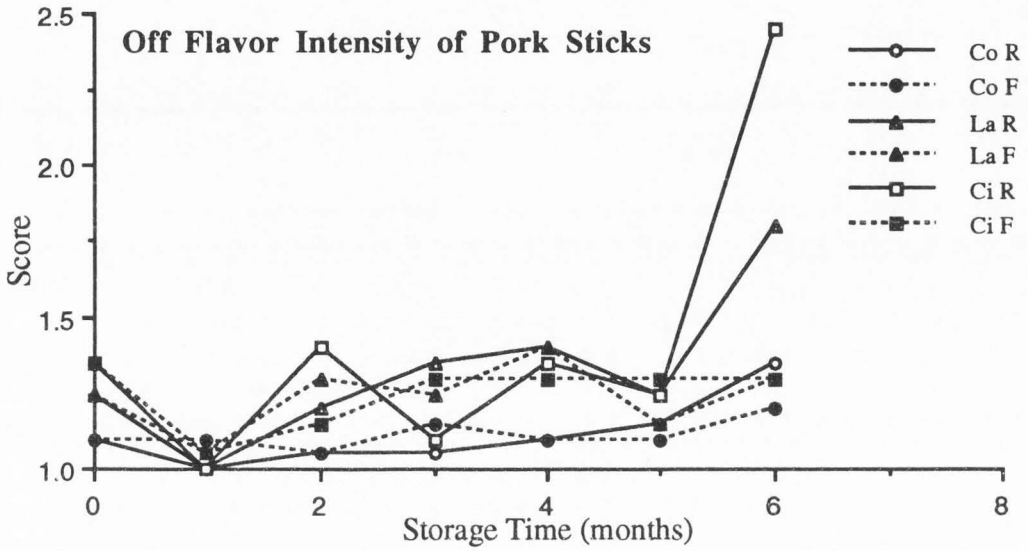

Figure 10. Off-flavor intensity of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = high intensity, 1 = not detectable. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = Frozen.

samples (Figure 11). However, for all three treatments stored at 2°C, overall acceptability scores significantly decreased ($p < 0.01$) from five to six months storage. Pork sticks formulated with citric acid had the lowest overall acceptability scores after six months storage. The control samples showed the least decrease in overall acceptability during storage.

Table 3 shows microbial plate counts for three treatments made from blade meat over all storage times at three different temperatures. Those pork sticks dipped with potassium lactate for 30 seconds and stored at 22°C were unacceptable after one month storage. The aerobic plate count of the control was 7.88 (log CFU / g), which is considered spoilage level. Addition of potassium lactate or citric acid lowered the aerobic plate counts of pork sticks to 4.23 (log CFU / g) and 5.76 (log CFU / g), respectively. However, oxidative rancidity was a problem for all three treatments held at room temperature, due to the exposure of these samples to the ambient environment. Microbial plate counts (both aerobic and anaerobic) did not change in all three treatments vacuum-packaged and stored at 2°C or -20°C.

In experiment 2, samples held at room temperature were not vacuum-packaged, due to concern that botulism might develop. However, work by Leistner et al. (1981) has indicated that cooked meat may safely be vacuum-packaged and stored at room temperature if the pH is less than 5.2, and a_w is less than 0.95. Accordingly, experiment 3 was done to measure sensory attributes of vacuum-packaged pork sticks during storage at 22°C, after formulation with three levels of citric acid, which lowered product pH to 5.02, 5.12, and 5.18. Only one replicate was done, so there was no true error on the ANOVA tables of statistic analysis. Table 4 shows the moisture content, protein content, fat content, a_w, and pH of the three treatments. There was no significant difference among treatments for the aforementioned measurements. There was no

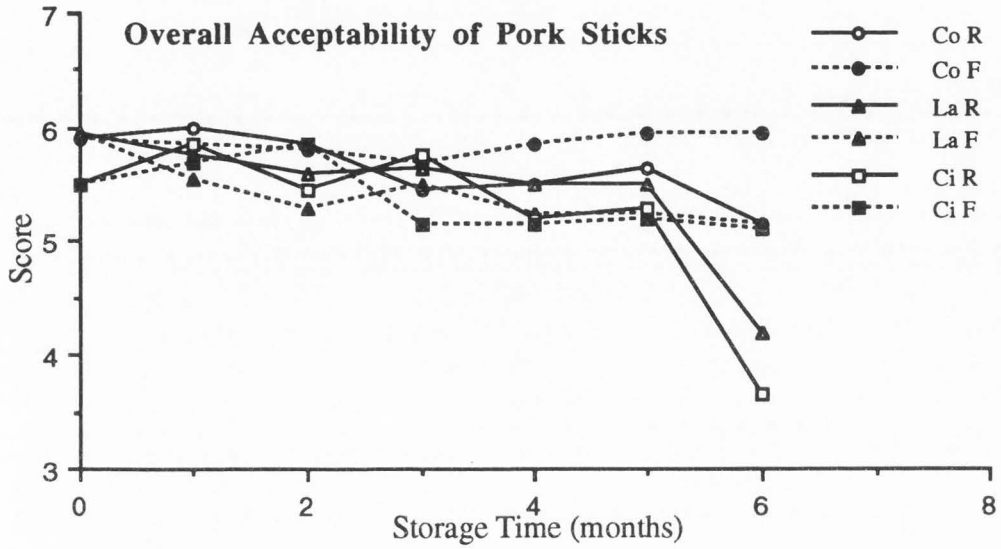

Figure 11. Overall acceptability of vacuum-packaged pork sticks stored frozen (-20°C) or refrigerated (2°C) for 6 months (experiment 2). Scores: 7 = very acceptable, 1 = very unacceptable. Co: control samples, La: lactate added (3%), Ci: citric acid added (0.5%), R = refrigerated, F = frozen.

Table 3. Microbial plate counts of pork sticks (made of blade meat) stored at room temperature (22°C), frozen (-20°C), or refrigerated (2°C) for 6 months (experiment 2). Pork sticks stored at 22°C were not vacuum packaged. Refrigerated or frozen samples were vacuum packaged.

Storage Temp.	Treatment	Initial	Storage Time (months)											
			1		2		3		4		5		6	
		APC[2]	APC	ANPC[3]	APC	ANPC	APC	ANPC	APC	ANPC	APC	ANPC	APC	ANPC
22°C	Control	3.72[1]	7.88											
	Lactate	3.71	4.23											
	Citrate	3.74	5.76											
2°C	Control	3.72	3.66	< 2[4]	3.59	< 2	3.60	< 2	3.71	< 2	3.56	< 2	3.67	< 2
	Lactate	3.71	3.72	< 2	3.59	< 2	3.64	< 2	3.62	< 2	3.52	< 2	3.63	< 2
	Citrate	3.74	3.69	< 2	3.49	< 2	3.54	< 2	3.49	< 2	3.61	< 2	3.73	< 2
-20°C	Control	3.72					3.71	< 2					3.61	< 2
	Lactate	3.71					3.69	< 2					3.63	< 2
	Citrate	3.74					3.63	< 2					3.54	< 2

[1] All values are log colony forming units (CFU) / g meat

[2] APC: aerobic plate count

[3] ANPC: anaerobic plate count

[4] < 2: plate at the lowest dilution (10^{-2}) had 1 or 0 CFU, ie less than 100 CFU / g meat, or less than log 10^2 CFU / g meat.

Table 4. Moisture content, protein content, fat content, a_w, and pH of pork sticks made with 3 different levels of citric acid (experiment 3).

Treatment	% Moisture	% Protein	% Fat	a_w	pH
Citrate 0.56%	28.17	47.46	13.55	0.79	5.18
Citrate 0.60%	28.16	47.35	14.13	0.80	5.12
Citrate 0.66%	28.06	47.24	14.47	0.79	5.02

All the values are the average of duplicate samples.

significant difference observed among treatments for all sensory attributes over three months storage. Color uniformity of the three treatments fluctuated during three months storage due to the gradual discoloration (Figure 12). All three treatments had a steep decrease ($p < 0.01$) in red color intensity beyond one month storage (Figure 13). Contrary to red color intensity, brown color intensity of the treatments increase rapidly ($p < 0.01$) beyond one month storage (Figure 14). Texture of the treatments became very hard ($p < 0.05$) beyond two months storage (Figure 15). Spicy flavor of these samples showed no significant change over three months storage (Figure 16). Acid flavor intensity of the samples decreased (Figure 17) with increasing storage time ($p < 0.01$). A steep increase ($p < 0.01$) was shown in rancid flavor intensity of the samples beyond two months storage (Figure 18). Off-flavor intensity of the samples appeared to increase similarly ($p < 0.01$) during storage (Figure 19). Overall acceptability of the samples decreased rapidly ($p < 0.01$) after two months storage (Figure 20).

Table 5 shows the microbial plate counts of these treatments over three months storage. These samples, regardless of treatment, were evaluated as unacceptable after three months storage even though the microbial plate counts of these samples did not increase during storage. In the TBA assay (Figure 21), the malonaldehyde concentration of the samples did not significantly change, even though the trained panelists gave higher scores for rancidity to samples stored for three months. The rancid flavor may be caused by organic compounds other than malonaldehyde.

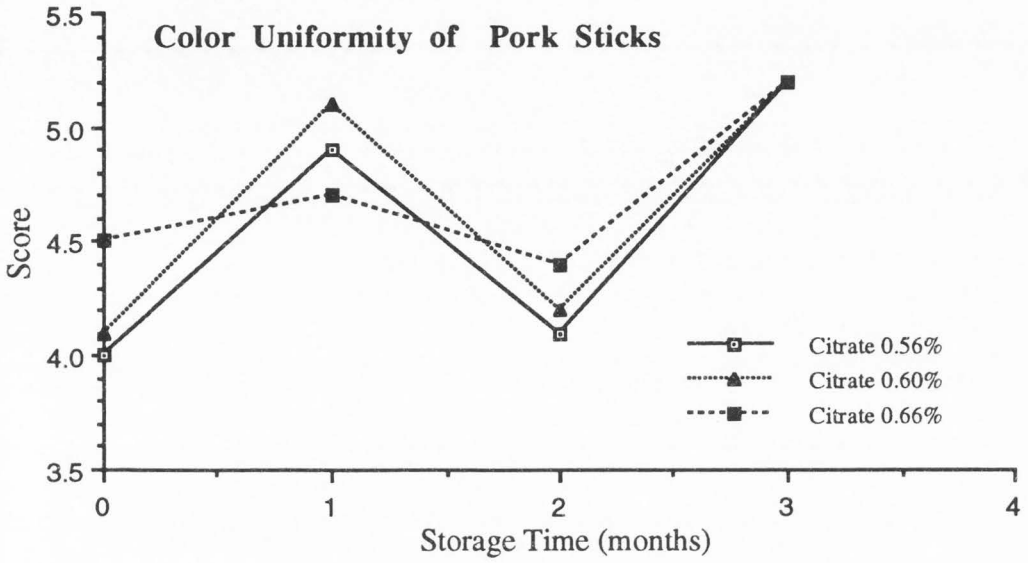

Figure 12. Color uniformity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = very uniform, 1 = very spotted or discolored.

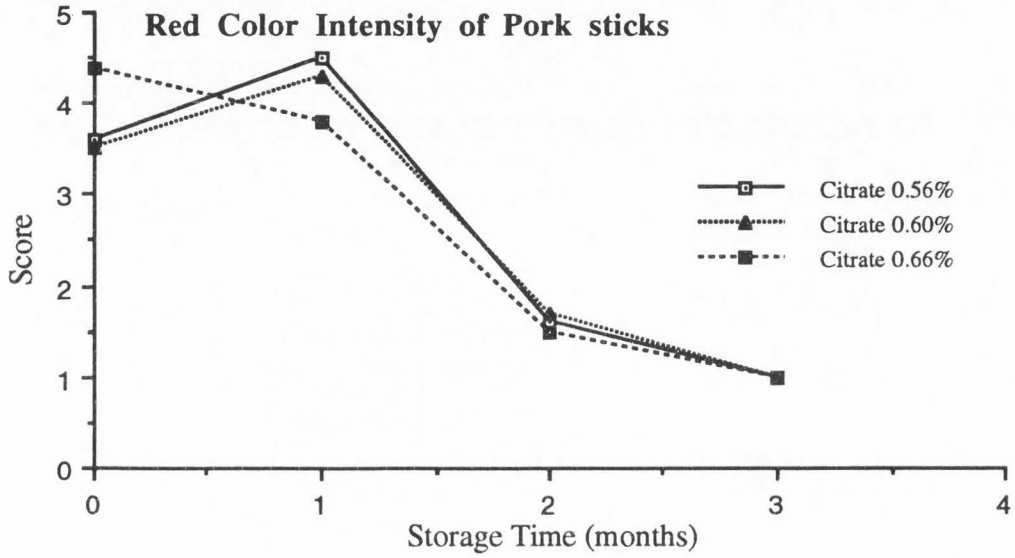

Figure 13. Red color intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = very intensely red, 1 = not red.

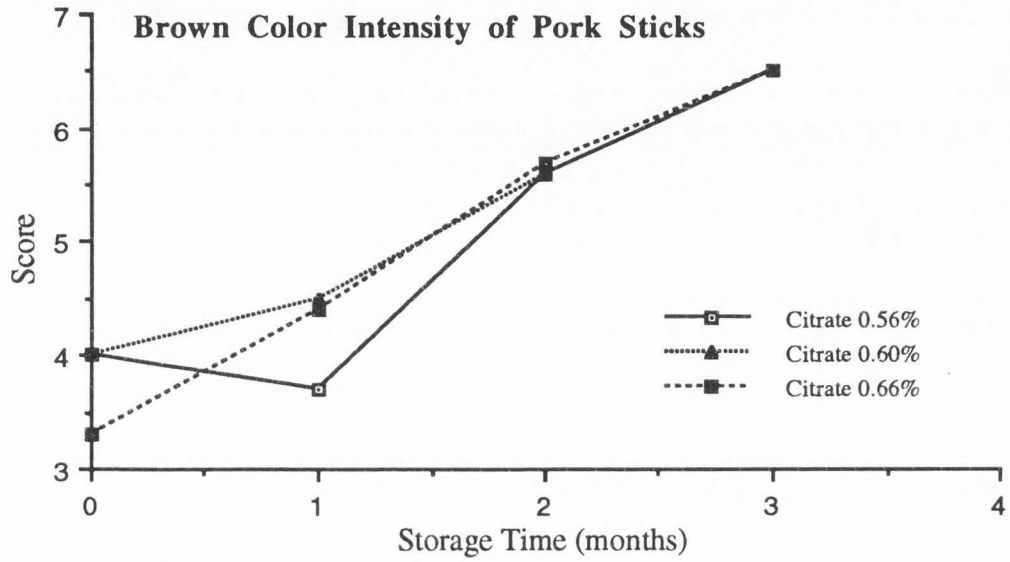

Figure 14. Brown color intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = very intensely brown, 1 = not brown.

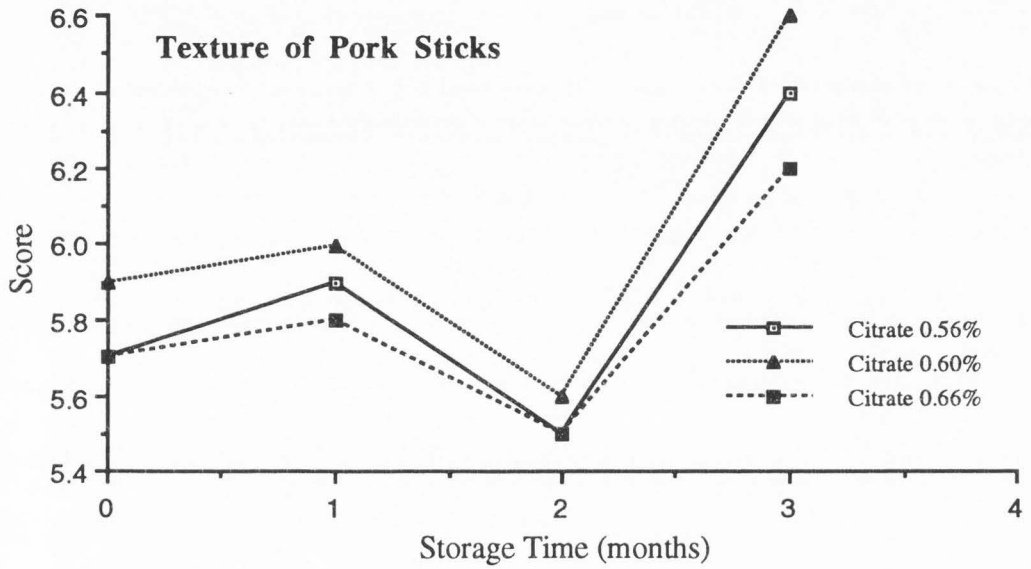

Figure 15. Texture of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = very hard, 1 = very soft.

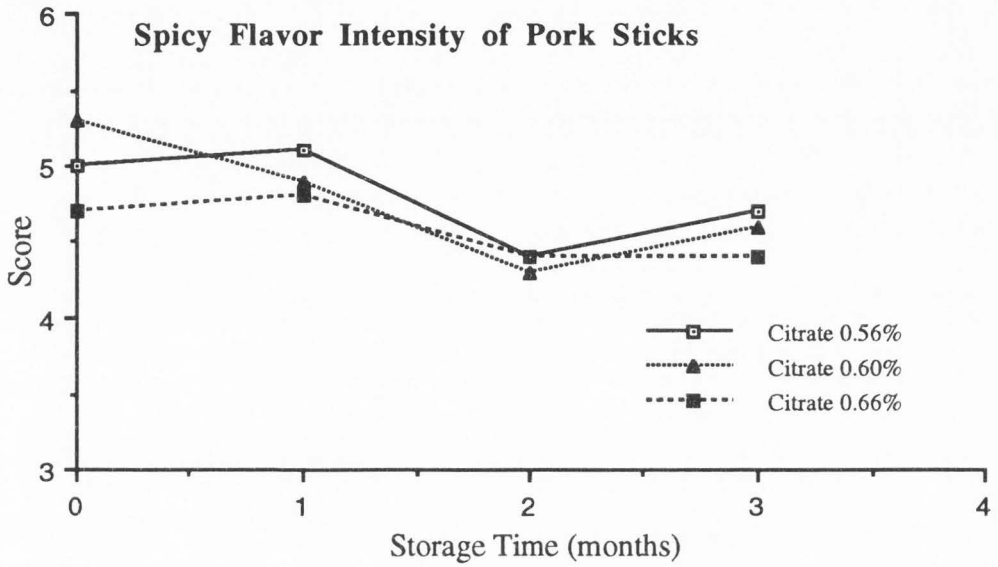

Figure 16. Spicy flavor intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = high intensity, 1 = not detectable.

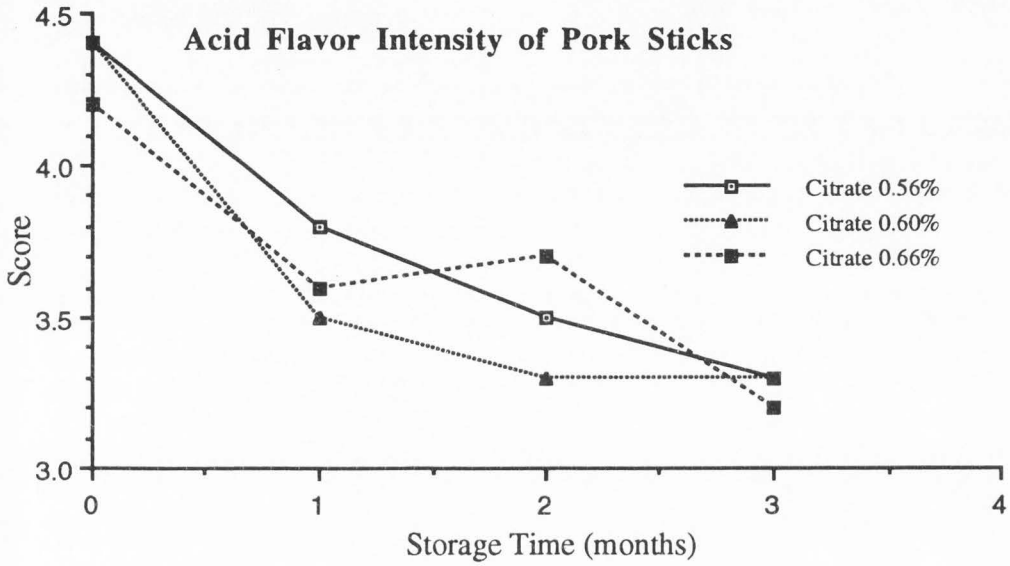

Figure 17. Acid flavor intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Score: 7 = high intensity, 1 = not detectable.

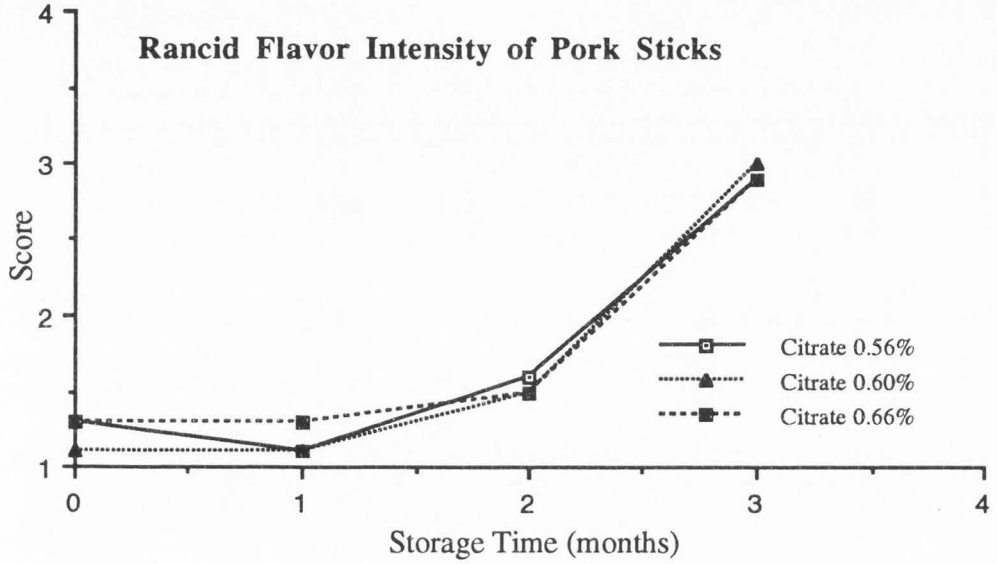

Figure 18. Rancid flavor intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Score: 7 = high intensity, 1 = not detectable.

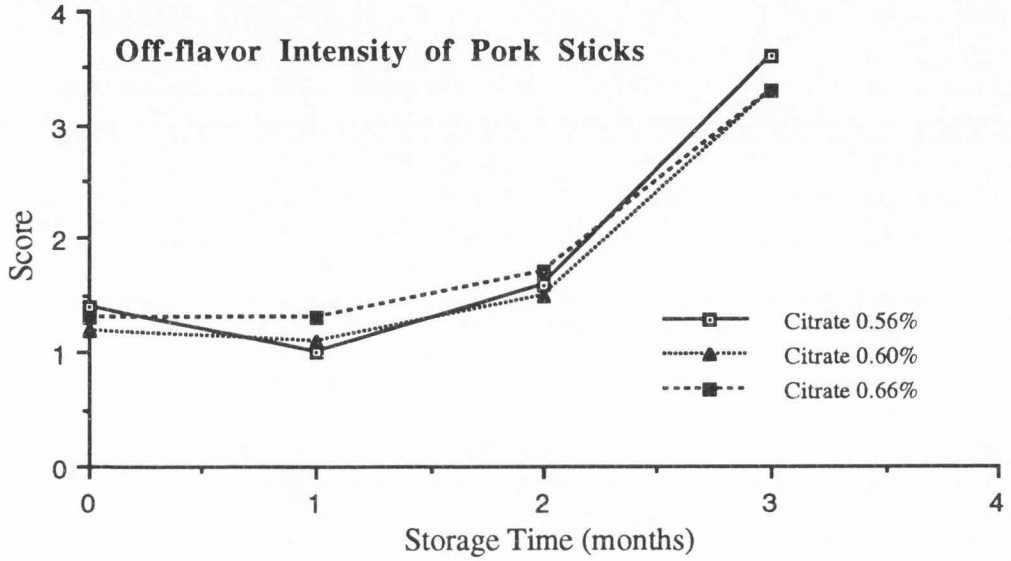

Figure 19. Off-flavor intensity of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = high intensity, 1 = not detectable.

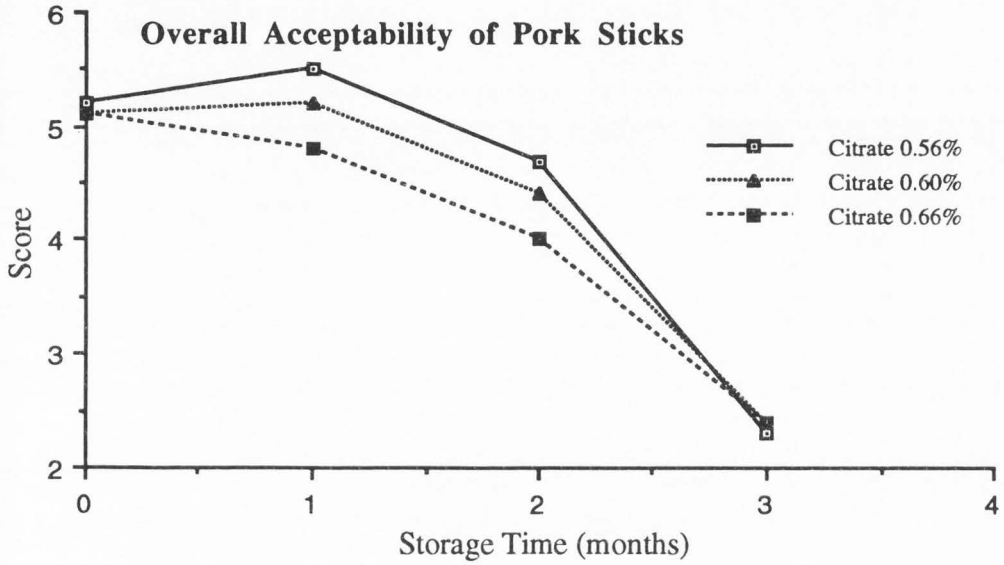

Figure 20. Overall acceptability of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3). Scores: 7 = very acceptable, 1 = very unacceptable.

Table 5. Microbial plate counts of pork sticks formulated with 3 different levels of citric acid during 3 months storage (experiment 3).

Storage Temp.	Treatment	Initial	Storage time (months)					
			1		2		3	
		APC[2]	APC	ANPC[3]	APC	ANPC	APC	ANPC
22°C	Citrate.56%	3.56[1]	3.58	< 2[4]	3.60	< 2	3.75	< 2
	Citrate.60%	3.58	3.65	< 2	3.48	< 2	3.72	< 2
	Citrate.66%	3.54	3.68	< 2	3.48	< 2	3.57	< 2

[1] All values are log colony forming units (CFU) / g meat.

[2] APC = aerobic plate count.

[3] ANPC = anaerobic plate count.

[4] < 2: plates at the lowest dilution (10^{-2}) had 1 or 0 CFU, ie, less than 100 CFU / g, or less than log 10^2 CFU / g meat.

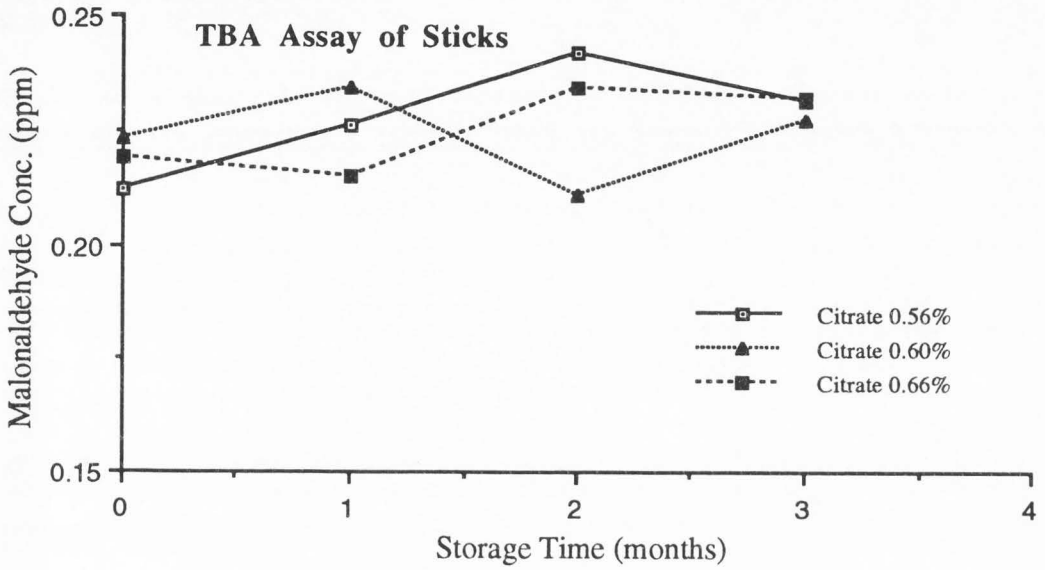

Figure 22. Malonaldehyde concentration of vacuum-packaged pork sticks stored at room temperature (22°C) for 3 months (experiment 3).

DISCUSSION

In experiment 1, the consumer panel preferred lean pork sticks made from blade meat over greasy pork sticks made from 80:20 trim regardless of the addition of potassium lactate or citric acid. The high-fat pork sticks were unacceptable to the consumer panel. A relatively low moisture content (about 34%) was found for control samples in this experiment. Preliminary tests showed that samples with higher moisture content (about 42%) had bacterial spoilage after two months storage. Different raw materials and longer cooking times for products in experiment 1 may explain the differences in moisture content, compared to the preliminary experiments. The raw materials used for preliminary work were sow meat while blade meat and 80:20 trim were used in this study.

The control blade meat samples in experiment 1 and 2 had water activity of 0.87. The addition of potassium lactate and citric acid lowered the water activity of the pork sticks to 0.80 and 0.83, respectively. The decrease in water activity with addition of potassium lactate agreed with the study of Chirife and Fortan (1980) that described a marked effect of sodium lactate in lowering water activity. The water activity lowering effect of the two additives may be explained by Rault's Law. The amount of free water in pork sticks was decreased by adding potassium lactate and citric acid. This caused the decrease of water vapor pressure and resulted in a lower water activity of the samples. In agreement with the study of Lamkey et al. (1991), the addition of lactate had no effect on the pH of the samples when compared to the control.

In experiment 2, according to the classification of Leistner et al. (1981) for meat products, the pork sticks required no refrigeration due to the $a_w < 0.91$. Therefore, it is not surprising that those samples stored at 2°C and -20°C did not get bacterial spoilage during six months storage. However, bacterial spoilage occurred in the control samples unpackaged and stored at 22°C. The water activity of the samples may have been raised

by dipping the samples in 2.5% potassium sorbate solution for 30 seconds even though they were dried before storage. Although addition of potassium lactate or citric acid significantly lowered the microbial load of the samples when compared to the control samples, oxidative rancidity still made these samples unacceptable after one month storage.

Sodium lactate has been shown to enhance flavor and increase color stability of cooked, vacuum-packaged beef roasts during refrigerated storage (Papadopoulos et al., 1991). Lamkey et al. (1991) found that formulation with sodium lactate reduced surface discoloration and off-odor development of fresh pork sausage chubs. However, in this study of cooked and cured pork sticks, incorporation of potassium lactate decreased the color uniformity and red color intensity and increased the brown color intensity of the samples. Also, the rancid flavor and off-flavor intensity increased and overall acceptability decreased after five months storage at 2°C. Similar results occurred to the samples with added citric acid that were stored at 2°C. Addition of potassium lactate or citric acid may influence the raw meat emulsion and lower the color uniformity and red color intensity of the final products.

In experiment 3, all samples, regardless of citrate level, had a much lower moisture content, compared with the control samples of experiment 1 and 2. The addition of citric acid may lower the pH close to the isoelectric point of the meat proteins and facilitate dehydration during cooking. Due to the low water activity of the samples, the microbial loads stayed at the initial level during three months storage. However, the bags used to vacuum package the samples may be not suitable for ambient temperature storage as shown by the browning of these samples beyond one month storage. Failure to remove all the air from the packages when packaging may be the other reason to explain the browning of the samples. Hardening of the samples beyond two months storage may be caused by some water loss during storage, even though samples were

vacuum-packaged. The concentration of malonaldehyde did not change as measured by TBA assay during three months storage. Some trained panelists commented that samples were unacceptable because of the brown color. Therefore, the low rancid and off-flavor intensity panel ratings may have been influenced by sample discoloration. Also, the rancid flavor may have been caused by organic compounds other than malonaldehyde.

Based on ingredient costs (shown in Appendix E Table E1), pork sticks made from blade meat cost $3.15 to produce, excluding labor, packaging, and overhead. Since jerky retails for up to $22/lb, pork sticks can be produced at a competitive cost.

CONCLUSIONS

The results of consumer evaluation showed preference for the pork sticks made from blade meat, but not for those made from 80:20 trim. Incorporation of potassium lactate or citric acid in the samples did not influence the consumer evaluation scores, but did decrease the overall acceptability ratings by trained panelists after five months storage of the samples stored at 2°C. According to the classification of Leistner et al. (1981) for meat products, freezing and refrigeration are not necessary for this product due to the low water activity (0.874) of less than 0.91. However, the minimum a_w for growth of Staphylococcus aureus was reported to be 0.86 (Lotter and Leistner, 1978). Thus, additives such as potassium lactate or citric acid may be needed to reduce water activity and pH, respectively, thus extending shelf life for pork sticks stored at ambient temperature. The use of vacuum-packaging materials impermeable to oxygen and water is suggested in order to avoid oxidative rancidity.

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APPENDICES

APPENDIX A

Pork Stick Spicy Formula

Ingredients	Weight
Coarsely ground pork	20 lb
Salt	125 g
Red Pepper	5 g
Black Pepper	35 g
Garlic Power	4 g
Dill	4 g
Prague Powder(6.25% sodium nitrite)	22 g
Potassium Lactate	272 g (3.0%)
Encapsulated Citric Acid	45 g (0.5%), 51 g (0.56%), 55 g (0.60%), 60 g (0.66%)

APPENDIX B

Pork Stick Evaluation Date_____

Name_____

Please evaluate the pork sticks in same order as they are listed below using a 1-9 Hedonic scale. Rinse your mouth out between samples.

Like extremely----------9	Dislike slightly-----------4
Like very much---------8	Dislike moderately-------3
Like moderately---------7	Dislike very much--------2
Like slightly----------6	Dislike extremely---------1
Neither like or dislike--5	

Sample #	Score
_____	_____
_____	_____
_____	_____

APPENDIX C

Pork Stick Evaluation (trained panel)

Please evaluate pork sticks for the following attributes and feel free to use any number 1-7, even if no description is associated with that number.

1. Color Uniformity:

7 Very uniform
6
5 Slightly spotted or discolored
4
3 Moderately spotted or discolored
2
1 Very spotted or discolored

2. Red Color Intensity:

7 Very Intensely Red
6
5 Moderately Red
4
3 Slightly red
2
1 Not red

3. Brown Color Intensity:

7 Very intensely brown
6
5 Moderately brown
4
3 Slightly brown
2
1 Not brown

4. Texture:

7 Very hard
6
5 Slightly hard
4
3 Slightly soft
2
1 Very soft

5. Spicy Flavor, 6. Acid Flavor, 7. Rancid Flavor, and 8. Off-flavor:

7 high intensity
6
5 Moderate intensity
4
3 Low intensity
2
1 Not detectable

9. Overall Acceptability:

7 Very acceptable
6
5 Slightly acceptable
4

3 Slightly unacceptable

2

1 Very unacceptable

		Sample #					
	Attribute						
1	Color uniformity						
2	Red color intensity						
3	Brown color intensity						
4	Texture						
5	Spicy flavor						
6	Acid flavor						
7	Rancid flavor						
8	Off-flavor						
9	Overall acceptability						

Comments:

APPENDIX D

Analysis of Variance Tables

Table D1. Analysis of variance for hedonic scores of pork sticks (experiment 1).

SOURCE	DF	MS	F
Replication(R)	1	4.98	2.97
Treatment(T)	5	1795.33	214.12*
RxT	5	50.35	6.01*
Error	552	925.66	
Total	563		

* Significant at $p < 0.01$

Table D2. Analysis of variance for color uniformity score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	33.03	28.18*
Temperature	1	2.01	1.71
Time	5	1.90	1.62
Treat.xTemp.	2	0.34	0.29
Treat.xTime	10	0.52	0.44
Temp.xTime	5	0.95	0.81
Treat.xTemp.xTime	10	0.28	0.24
Replication	36	1.17	0.98
Error	648	1.19	
Total	719		

* Significant at $p < 0.001$

Table D3. Analysis of variance for red color score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	35.90	22.66**
Temperature	1	0.73	0.98
Time	5	6.28	3.96*
Treat.xTemp.	2	0.63	0.85
Treat.xTime	10	0.53	0.71
Temp.xTime	5	2.45	1.55
Treat.xTemp.xTime	10	0.42	0.63
Replication	36	1.58	1.00
Error	648	0.75	
Total	719		

* Significant at $p < 0.01$
** Significant at $p < 0.001$

Table D4. Analysis of variance for brown color score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	23.13	16.54**
Temperature	1	0.11	0.08
Time	5	8.64	6.17**
Treat.xTime	2	1.16	0.83
Treat.xTime	10	0.82	0.59
Temp.xTime	5	4.06	2.90
Treat.xTemp.xTime	10	0.43	0.30
Replication	36	1.40	1.00
Error	648	0.84	
Total	719		

** Significant at $p < 0.001$

Table D5. Analysis of variance for texture score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

Source	DF	MS	F
Temperature	1	25.31	12.36*
Treatment	2	1.52	0.74
Time	5	19.52	9.53**
Treat.xTemp.	2	0.82	0.40
Treat.xTime	10	0.61	0.30
Temp.xTime	5	0.57	0.28
Treat.xTemp.xTime	10	0.24	0.12
Replication	36	2.05	1.00
Error	648	1.00	
Total	719		

* Significant at $p < 0.01$
** Significant at $p < 0.001$

Table D6. Analysis of variance for spicy flavor score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Temperature	1	10.04	6.97*
Treatment	2	5.87	4.08
Time	5	5.55	3.85**
Treat.xTemp.	2	0.27	0.69
Treat.xTime	10	0.54	0.38
Temp.xTime	5	1.64	1.34
Treat.xTemp.xTime	10	0.61	0.42
Replication	36	1.44	1.00
Error	648	1.05	
Total	719		

* Significant at $p < 0.05$
** Significant at $p < 0.01$

Table D7. Analysis of variance for acid flavor score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	48.88	49.07*
Temperature	1	5.51	5.53
Time	5	0.92	0.92
Treat.xTemp.	2	0.38	0.38
Treat.xTime	10	0.24	0.24
Temp.xTime	5	0.96	0.96
Treat.xTemp.xTime	10	0.95	0.95
Replication	36	1.00	1.00
Error	648	2.15	
Total	719		

* Significant at $p < 0.001$

Table D8. Analysis of variance for rancid flavor of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	1.25	4.00*
Temperature	1	1.61	5.12*
Time	5	2.18	6.96**
Treat.xTemp.	2	0.33	1.07
Treat.xTime	10	0.34	1.09
Temp.xTime	5	1.32	4.20
Treat.xTemp.xTime	10	0.09	0.29
Replication	36	0.31	1.00
Error	648	0.21	
Total	719		

* Significant at $p < 0.05$
** Significant at $p < 0.001$

Table D9. Analysis of variance for off-flavor score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	3.04	5.07*
Temperature	1	1.61	2.68
Time	5	3.75	6.24**
Treat.xTemp.	2	0.55	0.92
Treat.xTime	10	0.56	0.93
Temp.xTime	5	1.92	3.19
Treat.xTemp.xTime	10	0.53	0.89
Replication	36	0.60	1.00
Error	648	0.20	
Total	719		

* Significant at $p < 0.05$
** Significant at $p < 0.001$

Table D10. Analysis of variance for overall acceptability score of vacuum-packaged pork sticks as influenced by treatment, storage temperature, and storage time (experiment 2).

SOURCE	DF	MS	F
Treatment	2	14.55	12.51**
Temperature	1	8.89	7.64*
Time	5	13.38	11.50**
Treat.xTemp.	2	0.02	0.02
Treat.xTime	10	2.26	1.94
Temp.xTime	5	5.95	5.11
Treat.xTemp.xTime	10	1.08	0.93
Replication	36	1.16	1.00
Error	648	0.76	
Total	719		

* Significant at $p < 0.01$
** Significant at $p < 0.001$

Table D11. Analysis of variance for color uniformity score of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.23	0.14
Time	3	7.40	4.42*
Treat.xTime	6	0.37	0.22
Error	108	1.68	
Total	119		

* Significant at $p < 0.01$

Table D12. Analysis of variance for brown color score of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.48	0.55
Time	3	48.10	55.56*
Treat.xTime	6	1.03	1.19
Error	108	0.87	
Total	119		

* Significant at $p < 0.001$

Table D13. Analysis of variance for red color score of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.03	0.05
Time	3	76.28	107.68*
Treat.xTime	6	1.27	1.79
Error	108	0.71	
Total	119		

* Significant at $p < 0.001$

Table D14. Analysis of variance for texture score of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	1.81	2.62
Time	3	3.93	5.69*
Teat.xTime	6	0.31	0.45
Error	108	0.69	
Total	119		

* Significant at $p < 0.01$

Table D15. Analysis of variance for spicy flavor of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	2.43	2.40
Time	3	3.22	3.19*
Treat.xTime	6	0.28	0.28
Error	108	1.01	
Total	119		

* Significant at $p < 0.05$

Table D16. Analysis of variance for acid flavor score of vacuum-packaged pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.16	0.09
Time	3	6.32	3.68*
Treat.xTime	6	0.21	0.12
Error	108	1.72	
Total	119		

* Significant at $p < 0.05$

Table D17. Analysis of variance for rancid flavor score of pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.06	0.05
Time	3	20.50	18.42*
Treat.xTime	6	0.09	0.08
Error	108	1.11	
Total	119		

* Significant at $p < 0.01$

Table D18. Analysis of variance for off-flavor score of pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	0.21	0.16
Time	3	32.81	25.92*
Treat.xTime	6	0.18	0.14
Error	108	1.27	
Total	119		

* Significant at $p < 0.001$

Table D19. Analysis of variance for overall acceptability score of pork sticks stored at room temperature as influenced by treatment and storage time (experiment 3).

SOURCE	DF	MS	F
Treatment	2	3.03	4.99
Time	3	54.36	89.37*
Treat.xTime	6	1.32	2.17
Error	108	0.61	
Total	119		

* Significant at $p < 0.001$

APPENDIX E

Ingredient Costs

Table E1. Ingredient costs.

Item	Price ($/lb)	Price/20 lb batch (meat basis)
Pork Blade Meat	1.03	20.60
80:20 Pork Trim	0.79	15.8
Salt	0.10	0.027
Red Pepper	2.89	0.031
Black Pepper	3.65	0.281
Garlic Powder	3.20	0.028
Dill	3.20	0.028
Prague Powder	0.39	0.018
Potassium Lactate	1.05	0.62
Encapsulated Citric Acid	4.00	0.396